Patent Application

of

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for

# Seed Layer Structure for Improved Crystallographic Orientation of a Hard Magnetic Material

## FIELD OF THE INVENTION

The present invention relates generally to a seed layer structure for improved crystallographic orientation in a hard magnetic material. More particularly, the present invention relates to a seed layer structure for providing an improved longitudinal bias magnetic field or hard bias for a sense layer in a magnetic sensor such as that in a magnetic read head used in magnetic recording.

## BACKGROUND OF THE INVENTION

In a hard disk drive, a magnet write transducer or head is used to write and thus store information as magnetic bits on a spinning magnetic disk. The magnetic bits are regions on the

magnetic disk with a net magnetization and having north and south poles where a magnetic field exits or enters the magnetic bits. During the writing of the magnetic bits, the magnetic write head is positioned in proximity of the spinning magnetic disk. More precisely, the magnetic write head is mounted on a slider that flies over the spinning magnetic disk on an airbearing. The slider is kept over an appropriate track of the magnetic disk by a servo control system. The magnetic bits, and thus the information, is read by positioning a magnetic read transducer or head in proximity above the spinning magnetic disk and over the appropriate track by the same slider and servo control system. The magnetic field associated with the magnetic bits outside of the magnetic disk (henceforth called the external magnetic field) enters the magnetic read head and affects a magnetic sensor in the magnetic read head such that a measurable output corresponding to the magnetic bits is produced. Magnetic sensors based on the fundamental principles of magnetoresistance including anisotropic magnetoresistance (AMR), giant magnetoresistance (GMR) or spin valve and spin tunneling have been well known in the art for some time. Magnetic read heads incorporating these magnetic sensors have also been produced and widely used. For examples, see US Pat. Nos. 5,159,513 and 5,206,590.

The areal density of the magnetic disk corresponds to the number of magnetic bits per unit area. There is an ongoing demand for storing more information on a given disk and thus for increasing the areal density. Magnetic scaling is a well-known approach in the art for achieving higher areal density while maintaining the signal-to-noise ratio that is ultimately necessary to obtain the measurable output from the magnetic read head corresponding to the magnetic bits. For example, according to the magnetic scaling approach the dimensions associated with magnetic recording, such as the thickness of various layers in the magnetic read head, need to be reduced as the areal density is increased. As discussed below, however, not all the consequences of the magnetic scaling approach are fully appreciated in the art.

Fig. 1 shows an illustration of a prior art magnetic read head based on a typical GMR magnetic sensor as seen from the airbearing surface. The magnetic sensor has a high coercivity

ferromagnetic pinned layer **112** (such as an alloy of NiFe) with a net magnetization whose direction pointing into the page is fixed and a low coercivity ferromagnetic free layer **116** (such as an alloy of NiFe) with a net magnetization whose direction is moveable, rotating from pointing into the page to pointing out of the page in response to the external magnetic field from the magnetic disk. The direction of the magnetization in the ferromagnetic pinned layer **112** is fixed by exchange coupling with an antiferromagnetic layer **110**. For a current **113** in-plane (CIP) magnetic sensor such as that shown in Fig. 1, the ferromagnetic pinned layer **112** and the ferromagnetic free layer **116** are separated by a thin film of copper **114** or other non-magnetic metal with a relatively long electron mean free path. The variation in the resistance of the GMR magnetic sensor in response to the rotation of the direction of the magnetization in the ferromagnetic free layer **116** is known in the art. It is this variation that gives rise to the measurable output from the magnetic sensor in the magnetic read head corresponding to the magnetic bits written on the magnetic disk.

An important concern in the design of the magnetic sensor in Fig. 1 is a longitudinal bias magnetic field applied to the ferromagnetic free layer **116** by the high coercivity hard magnet **118** at the two side edges of the ferromagnetic free layer **116**. Longitudinal direction is the direction in the plane of the airbearing surface and parallel to the layers of the magnetic sensor, i.e., from right to left in Fig. 1, as indicated by the arrow **120**. The longitudinal bias magnetic field is essential to proper operation of the magnetic sensor by ensuring that the ferromagnetic free layer **116** has a single magnetic domain. In the absence of the longitudinal bias magnetic field, the magnetic moments in the ferromagnetic free layer **116** tend to establish a magnetic multi-domain state. As is known in the art, when the ferromagnetic free layer **116** is allowed to have more than one magnetic domain it experiences Barkhausen jumps and other magnetic domain reorientation phenomena during magnetic reversal when the magnetic sensor is responding to the external magnetic field from the magnetic disk. This situation is highly undesirable since it produces noise and lowers the signal-to-noise ratio of the magnetic sensor and thus the ability to produce the measurable output corresponding to the magnetic bits.

A variety of schemes have been employed to provide the longitudinal bias magnetic field and prevent Barkhausen noise. Fig. 1 illustrates one of the more common approaches, so-called hard bias associated with the hard magnet **118** on either side of the ferromagnetic free layer **116**. For more details on hard bias see US Pat. No. 5,729,410.

In the course of manufacturing magnetic sensors, such as that shown in Fig. 1, it is common for the hard magnet **118** that is used to provide the hard bias to taper at the interface with the ferromagnetic free layer **116**. As shown in Fig. 1, this taper produces a tip **122** of the hard magnet **118** on either side of the ferromagnetic free layer **116**. Regions such as the tip **122** of the hard magnet **118** have negative consequences for the performance and the scaling of the magnetic sensor.

It is known in the art that superior materials for the hard magnet **118** should exhibit high coercivity, high remnant magnetization and the magnetic c-axis should be confined parallel to the film plane (henceforth called in-plane) as opposed to perpendicular to the film plane (henceforth called out-of-plane). These properties strongly depend on the microstructural characteristics of the hard magnet **118**, which are in turn sensitive to growth conditions, film thickness and the ancillary non-magnetic layers (so-called seed layers or underlayers) onto which said hard magnet **118** is deposited. Achieving confinement of the magnetic axis in-plane is challenging and difficult in particular for very thin films in which the crystallographic growth is strongly dominated by early stages of nucleation. This situation is encountered at the tip **122** between the hard magnet **118** and the ferromagnetic free layer **116** and is also a general consequence of magnetic scaling, which dictates progressively smaller dimensions including thickness **124** of the hard magnet **118**.

Alloys of CoPt and CoPtCr grown on suitable materials offer a partial solution to this hard bias challenge and are widely used as the hard magnet **118**. If high temperatures are used during the deposition of the CoPtCr, grains with in-plane c-axis crystallographic orientation can be more easily obtained. Unfortunately, such high temperatures are incompatible with many of the other materials and techniques used to manufacture magnetic sensors and

magnetic read heads. As a consequence, some fraction of the magnetic grains in CoPtCr films used to provide hard bias in magnetic sensors have out-of-plane c-axis crystallographic orientation.

These grains with out-of-plane c-axis crystallographic orientation degrade the magnetic sensor performance. The problem is worsened as the dimensions of the magnetic sensor are reduced per the magnetic scaling approach on account of the superparamagnetic effect which results in a loss of the magnetic order when the magnetic grain volume drops below a critical value. In addition, unlike grains in the magnetic disk, which are magnetically decoupled from one another, there is strong exchange coupling between the grains in the hard magnet **118**. Furthermore, the average grain size in the hard magnet **118** is not typically scaled as the areal density is increased or, if it is decreased, the scaling ratio is larger than that dictated by the magnetic scaling approach. The combination of these effects increases the negative effect of grains in the hard magnet **118** with out-of-plane c-axis crystallographic orientation. This is especially the case in regions like the tip **122** where the number of grains is reduced as the overall magnetic sensor dimensions are scaled. Even if the average fraction of grains with out-of-plane c-axis crystallographic orientation remains fixed, the tip **122** may have a higher local fraction due to statistical fluctuations. These grains can act as nucleation sites for undesirable magnetic domains in the ferromagnetic free layer **116** with the deleterious effects described above.

One potential solution to this challenge is a seed layer, which improves the crystallographic properties of the hard magnet **118**. Fig. 2 shows an illustration of seed layer **126** that helps control the crystallographic orientation of grains in the hard magnet **118**. Cubic-titanium tungsten (see US Pat. No. 6,278,595), a bi-layer of tantalum-oxide and Cr (see US Appl. No. 2003/0058586 A1), Cr and alloys of CrMo have been used as the seed layer **126**.

Recent advances, however, in the magnetic sensor in magnetic read heads have made a simple seed layer, such as seed layer **126**, undesirable. In particular, the so-called ultra

contiguous junction (UCJ) arrangement in the magnetic sensor. As shown in Fig. 3, in the UCJ arrangement the hard magnet **118** that provides hard bias is collinear with the ferromagnetic free layer **116** thereby avoiding magnetic instabilities in the magnetic sensor. This, in turn, requires seed layer thickness **128** be increased up to around 15-25 nm. Since the seed layer is polycrystalline, at this thickness stress and crystallographic imperfections will degrade the ability of the seed layer **126** to improve the c-axis crystallographic orientation of the grains in the hard magnet **118**. This problem is illustrated in Fig. 4, which shows measured x-ray intensity as a function of diffraction angle (twice the angle of incidence as measured from the normal to the film) at grazing incidence (which is sensitive to grains with out-of-plane c-axis crystallographic orientation) for two samples that are representative of current hard magnet **118** materials used for hard bias in magnetic sensors. The first sample has $Co_3Pt$ hard magnet **118** with thickness **124** of 7.6 nm and a CrMo seed layer **126** with seed layer thickness **128** of 12.0 nm. The x-ray diffraction data **152** for the first sample is shown in Fig. 4. The second sample has 3.0 nm thick Rh cap layer on CoPtCr hard magnet **118** with thickness **124** of approximately 18.0 nm and Cr seed layer **126** with seed layer thickness **128** of 10.0 nm. The x-ray diffraction data **162** for the second sample is also shown in Fig. 4. The presence of peaks corresponding to the $\langle 11\bar{2}0 \rangle$ direction in $Co_3Pt$ **170** and CoPtCr **180** are indicative of grains with out-of-plane c-axis crystallographic orientation.

In light of this discussion, there is a need to improve the crystallographic orientation of the grains in the hard magnet **118** that provides the longitudinal bias magnetic field to the ferromagnetic free layer **116** in magnetic sensors. Furthermore, there is a need to provide this improved crystallographic orientation of the grains in the hard magnet **118** with a relatively large thickness **128** seed layer **126**, such as is required in magnetic sensors with the UCJ arrangement.

## SUMMARY

Improving the crystallographic orientation of the grains in the hard magnet **118** that provides the longitudinal bias magnetic field to the ferromagnetic free layer **116** in magnetic sensors is secured in the present invention by a laminated seed layer structure with at least one interlayer and at least a first underlayer and a second underlayer, where the interlayer is located between the first underlayer and the second underlayer. The seed layer structure accommodates a relatively large total thickness as is required in magnetic sensors with the UCJ arrangement.

In an alternative embodiment of this invention, a second interlayer and a third underlayer are added to the seed layer structure. The second interlayer is located between the second underlayer and the third underlayer.

In another alternative embodiment of this invention, a third interlayer and a fourth underlayer are added to the seed layer structure. The third interlayer is located between the third underlayer and the fourth underlayer.

In yet another embodiment of this invention, a plurality of alternating additional pairs of layers, each pair of layers having an additional interlayer and an additional underlayer, are added to the seed layer structure. The additional interlayer in each pair is located between the underlayer from the previous pair of layers and the additional underlayer in the current pair of layers.

A detailed description of the invention and the preferred and alternative embodiments is presented below in reference to the attached drawing figures.

## BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a diagram illustrating an airbearing view of a magnetic sensor with hard bias as is known in the prior art.

Fig. 2 is a diagram illustrating a hard magnet with a seed layer as is known in the prior art.

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| Fig. 3 | is a diagram illustrating one side edge of a magnet sensor with the ultra contiguous junction (UCJ) arrangement as disclosed in the prior art. |
| Fig. 4 | is a diagram showing the measured x-ray intensity as a function of the diffraction angle at grazing incidence for two samples representative of the prior art. |
| Fig. 5 | is a diagram illustrating an embodiment of the invention. |
| Fig. 6 | is a diagram illustrating an embodiment of the invention. |
| Fig. 7 | is a diagram illustrating an embodiment of the invention. |
| Fig. 8 | is a diagram showing the measured x-ray intensity as a function of the diffraction angle at grazing incidence for two samples, each of which is a non-optimal embodiment of the present invention. |
| Fig. 9 | is a diagram showing the measured x-ray intensity as a function of the diffraction angle at grazing incidence for two samples, each of which is an embodiment of the present invention. |
| Fig. 10a | is a diagram showing an in-plane magnetic hysteresis loop measured in a VSM for a sample representative of the prior art with the magnetic field applied parallel to the plane of the film (in-plane). Both in-plane and out-of-plane magnetization components are detected during acquisition of the hysterisis loop. |
| Fig. 10b | is a diagram showing an out-of-plane magnetic hysteresis loop measured in a VSM for a sample representative of the prior art with the magnetic field applied parallel to the plane of the film (in-plane). Both in-plane and out-of-plane magnetization components are detected during acquisition of the hysterisis loop. |
| Fig. 10c | is a diagram showing an in-plane magnetic hysteresis loop measured in a VSM for a sample representative of an embodiment of this invention with the magnetic field applied parallel to the plane of the film (in-plane). Both in-plane |

and out-of-plane magnetization components are detected during acquisition of the hysterisis loop.

Fig. 10d is a diagram showing an out-of-plane magnetic hysteresis loop measured in a VSM for a sample representative of an embodiment of this invention with the magnetic field applied parallel to the plane of the film (in-plane). Both in-plane and out-of-plane magnetization components are detected during acquisition of the hysterisis loop.

## DETAILED DESCRIPTION OF THE EMBODIMENTS

An illustration of an embodiment of the invention is shown in Fig. 5. A hard magnet **210** with thickness **212** is deposited on a seed layer structure **200** comprised of at least a first underlayer **220** with a thickness **230**, a second underlayer **260** and a first interlayer **240** with a thickness **250** located between the first underlayer **220** and the second underlayer **260**. An illustration of another embodiment of the invention is shown in Fig. 6. An additional third underlayer **280** and second interlayer **270** are added to seed layer structure **265**, where the second interlayer **270** is located between the second underlayer **260** and the third underlayer **280**. An illustration of another embodiment of the invention is shown in Fig. 7. An addional fourth underlayer **300** and third interlayer **290** are added to seed layer structure **285**, where the third interlayer **290** is located between the third underlayer **280** and the fourth underlayer **300**. In a final embodiment of the invention (not shown), a plurality of alternating additional pair of layers, each with an interlayer and an underlayer, are added to the seed layer structure **285**. The additional interlayer in each pair is located between the underlayer from the previous pair of layers and the additional underlayer in the current pair of layers.

The material for the hard magnet **210** includes alloys of CoPt, such as $Co_YPt_{1-Y}$, where $0.25 \leq Y \leq 0.9$, and CoPtCr. Ion beam deposition and sputtering are suitable techniques for depositing the hard magnet **210**.

The material for the first underlayer **220** and the second underlayer **260** is typically a metal and includes Cr and alloys of CrMo ($Cr_XMo_{1-X}$, where $0.1 \le X \le 0.3$), alloys of CrMn ($Cr_XMn_{1-X}$), alloys of CrTi ($Cr_XTi_{1-X}$) and alloys of CrV ($Cr_XV_{1-X}$). The appropriate alloy is selected in part based on the need to closely match the lattice spacing of the material in the hard magnet **210** and the ability of the alloy to foster growth of the hard magnet **210** with the magnetic axis oriented in-plane. Specifically, body centered cubic (bcc) metals with crystallographic planes <200> growing in-plane and where the lattice mismatch with the hard magnet **210** is in the range 0-3%. An example includes $CrMo_{20}$. Ion beam deposition and sputtering are suitable techniques for depositing the first underlayer **220** and the second underlayer **260**.

The material for the first interlayer **240** is typically a dielectric and includes oxides of aluminum, oxides of tantalum, oxides of silicon and oxides of hafnium. Examples include $Al_2O_3$, $Ta_2O_3$, $SiO_2$, HfO and their thin-film, non-stoichiometric equivalents. Ion beam deposition is a suitable technique for depositing the first interlayer **240**.

While not shown in Figs. 5-7, an additional base layer of alumina beneath the first underlayer **220** in the seed layer structure **200** as well as a substrate, such as AlTiC, can be added as is known in the art.

Laminated structures with intercalated layers are used in the prior art to break up coherent growth and reduce strain especially in polycrystalline films and when a relatively large total thickness is desired. However, such laminated structures are primarily used to control grain size. In addition, simply forming a laminated structure is insufficient to achieve the benefits of this invention. This is illustrated in Fig. 8, which shows the measured x-ray intensity as a function of the diffraction angle at grazing incidence for two samples, each of which is a non-optimal embodiment of the present invention. A third sample has 2.0 nm thick Ta cap layer on $Co_3Pt$ hard magnet **210** with thickness **212** of 7.6 nm and with seed layer structure **200** comprised of CrMo first underlayer **220** with thickness **230** of 5.0 nm, Cr first

interlayer **240** with thickness **250** of 2.0 nm and CrMo second underlayer **260** with a thickness equal to thickness **230**. The x-ray diffraction data **412** for the third sample is shown in Fig. 8. A fourth sample has 2.0 nm thick Ta cap layer on $Co_3Pt$ hard magnet **210** with thickness **212** of 7.6 nm and with seed layer structure **265** comprised of CrMo first underlayer **220** with thickness **230** of 3.0 nm, Cr first interlayer **240** with thickness **250** of 1.0 nm and CrMo second underlayer **260** with a thickness equal to thickness **230**, Cr second interlayer **270** with a thickness equal to thickness **250** and CrMo third underlayer **280** with thickness equal to thickness **230**. The x-ray diffraction data **422** for the fourth sample is shown in Fig. 8. The presence of peak **424** in data **412** and **422** corresponding to the $<11\bar{2}0>$ direction in $Co_3Pt$ are indicative of grains with out-of-plane c-axis crystallographic orientation and the non-optimal nature of the seed layer structure **200** in the third sample and the seed layer structure **265** in the fourth sample.

The results presented in Fig. 8 should be contrasted with those in Fig. 9, which shows the measured x-ray intensity as a function of the diffraction angle at grazing incidence for two samples, each of which is an embodiment of the present invention. A fifth sample has 2.0 nm thick Ta cap layer on $Co_3Pt$ hard magnet **210** with thickness **212** of 7.6 nm and with seed layer structure **200** comprised of CrMo first underlayer **220** with thickness **230** of 5.0 nm, $Al_2O_3$ first interlayer **240** with thickness **250** of 1.0 nm and CrMo second underlayer **260** with a thickness equal to thickness **230**. The x-ray diffraction data **432** for the fifth sample is shown in Fig. 9. A sixth sample has 2.0 nm thick Ta cap layer on $Co_3Pt$ hard magnet **210** with thickness **212** of 7.6 nm and with seed layer structure **265** comprised of CrMo first underlayer **220** with thickness **230** of 3.0 nm, $Al_2O_3$ first interlayer **240** with thickness **250** of 1.0 nm and CrMo second underlayer **260** with a thickness equal to thickness **230**, $Al_2O_3$ second interlayer **270** with a thickness equal to thickness **250** and CrMo third underlayer **280** with thickness equal to thickness **230**. The x-ray diffraction data **442** for the sixth sample is shown in Fig. 9. The absence of peak **444** corresponding to the $<11\bar{2}0>$ direction in $Co_3Pt$

are indicative of grains with in-plane c-axis crystallographic orientation and the preferred nature of the seed layer structure **200** in the fifth sample and the seed layer structure **265** in the sixth sample.

Figs. 10a-d show magnetic hysteresis loops measured in a VSM for two samples with the magnetic field applied in-plane. The magnetization of the film is monitored with a vector coil arrangement that permits simultaneous detection of the in-plane (Figs. 10a and 10c) and out-of-plane (Figs. 10b and 10d) components of magnetization as the applied field is scanned. The in-plane and out-of-plane magnetic properties associated with the preferred and the non-preferred c-axis crystallographic orientation of the grains in hard magnet **210** are thereby measured. The magnetization in Figs. 10a-d is scaled to that of an equivalent thickness of NiFe. Using the index numbers from Fig. 2, a seventh sample is representative of the prior art, and has 2.0 nm thick Ta cap layer on $Co_3Pt$ hard magnet **118** with a thickness **124** of 7.6 nm and a CrMo seed layer **126** with seed layer thickness **128** of 12.0 nm. The in-plane **452** and out-of-plane **454** magnetic hysteresis loops are shown in Figs. 10a and 10b. Using the index numbers from Fig. 5, an eighth sample has 2.0 nm thick Ta cap layer on $Co_3Pt$ hard magnet **210** with thickness **212** of 7.6 nm and with seed layer structure **200** comprised of CrMo first underlayer **220** with thickness **230** of 5.0 nm, $Al_2O_3$ first interlayer **240** with thickness **250** of 1.0 nm and CrMo second underlayer **260** with a thickness equal to thickness **230**. The in-plane **462** and out-of-plane **464** magnetic hysteresis loops are shown in Figs. 10c and 10d. In agreement with the x-ray diffraction measurements shown in Figs 4 and 9, the seventh sample has an out-of-plane hysteresis loop **454** while the out-of-plane magnetic hysteresis loop **464** of the eighth sample is significantly suppressed. Specifically, the ratio of the in-plane and out-of-plane remnant magnetization for the seventh sample is approximately 80 while the ratio of the in-plane and out-of-plane remnant magnetization for the eighth sample is approximately 1200, an improvement of 15 fold.

Based on these results, it is clear that the seed layer structure **200** in this invention yields unexpected results: certain materials are suitable as the interlayer and not all underlayer and interlayer thicknesses work. For the interrlayer, the thickness **250** range is substantially between 0.1 nm to 10 nm. For example, for $Al_2O_3$ a typical value is 1 nm. The lower bound is set by that necessary to define a continuous film. The upper bound is determined by incoherence in the film. For the underlayer, the thickness **230** is substantially greater than 3 nm. For thickness **230** less than this value, the hard magnet **210** becomes magnetically unstable and the out-of-plane c-axis crystallographic orientation is not suppressed. The total thickness of the seed layer structure **200** is adjustable and can be dictated by the requirements of the UCJ arrangement in the magnetic sensor.

The examples provided in this invention have underlayers with the same underlayer thickness **230** and interlayers with the same interlayer thickness **250**. One skilled in the art may incorporate the advantages embodied in this invention in samples having multiple underlayers with different values of the underlayer thickness **230** so long as the underlayer thickness **230** of each underlayer in the seed layer structure **200** is substantially greater than 3 nm. Similarly, one skilled in the art may incorporate the advantages embodied in this invention in samples having multiple interlayers with different values of the interlayer thickness **250** so long as the interlayer thickness **250** of each interlayer in the seed layer structure **200** is substantially between 0.1 nm and 10 nm.

A wide variety of magnetic sensors that have hard bias will benefit from the seed layer structure **200** in this invention including those based on AMR, GMR, top spin valve, bottom spin valve, CIP **113**, current perpendicular to the plane (CPP) and magnetic tunnel junction or spin tunneling also known as tunnel valve sensors. For an example of a magnetic tunnel junction sensor see US Pat. No. 6,473,279. The invention benefits both hard bais structures with a single hard magnet **210** layer as well more complex hard bias structures with synthetic antiferromagnetic bias (for example, see US Pat. No. 6,266,218).

In summary, the seed layer structure **200** in this invention suppresses out-of-plane c-axis crystallographic orientation and accommodates a total thickness that meets the requirements of the UCJ arrangement in the magnetic sensor while preserving the other benefits such as an appropriate epitaxial relationship with the material in the hard magnet **210**.

In view of the above, it will be clear to one skilled in the art that the above embodiments may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.